An Overview of the Canadian Forces' Second Generation Capability-Based Planning Analytical Process

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Defence R&D Canada
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Technical Memorandum

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Abstract

In 2005, the Canadian Forces' (CF) Chief of Defence Staff announced the commencement of the transformation of the CF. As with any complex organization, transformation of its structure and processes is not simple. However, success of such a transition "depends upon leadership first identifying and understanding the thematic components of the past, and then, learning how to adapt and exploit the thematic strengths 'today' for the benefit of 'tomorrow' ". While several themes have been identified within the CF transformation, one in which the operational research community plays a vital support role is strategic decision-making. Strategic decision-making, in the context of defence acquisitions, has traditionally been described as a reactive process. In an effort to migrate defence acquisitions towards a more proactive process, a rational forward-looking decision-making process was developed: the Force Development (FD) process. At its core is Capability Based Planning (CBP), whose analytical process and associated tools provide decision-makers with an objective assessment of capability deficiencies, adequacies, and affluences. This objective assessment is central to the following defence acquisition trade-off analysis, whose output is a cost-effective strategic capability roadmap.

The FD process and first generation CBP analytical process have been recently reported. Development of the second generation CBP analytical process has been completed, which focused on advancement of the process and tools. In this technical memorandum a brief summary of the FD process is presented. This is followed by an overview of the second generation CBP analytical process, including a description of its methods with an emphasis on how they work together and their advancements since the first generation.

Résumé

En 2005, le Chef d'état-major de la Défense des Forces canadiennes (FC) a annoncé le début du processus de transformation des FC. Comme pour toute organisation complexe, la transformation de la structure et des processus n'est pas simple. Toutefois, pour assurer la réussite de cette transformation, « il faudra que les dirigeants déterminent et comprennent les éléments thématiques du passé et qu'ils apprennent à ensuite adapter et à exploiter les forces thématiques d'aujourd'hui afin de créer des occasions pour demain ». On a identifié plusieurs thèmes dans le cadre de la transformation des FC, dont celui de la prise de décisions stratégiques où la communauté de la recherche opérationnelle joue un rôle de soutien essentiel. La prise de décisions stratégiques dans le domaine des approvisionnements pour la Défense était généralement décrite comme un processus de réaction. Dans l'optique de rendre le processus d'approvisionnement de la Défense plus proactif, on a créé un processus rationnel de décision axé sur l'avenir : le processus de développement des forces (DF). La planification fondée sur les capacités (PFC), dont le processus analytique et les outils connexes offrent aux décideurs une évaluation objective des pénuries, des niveaux suffisants et des surplus en matière de capacités, est au cœur de ce processus. Cette évaluation objective est essentielle pour effectuer une analyse des différentes options en matière d'approvisionnement pour la Défense, puis créer une feuille de route des capacités stratégiques rentables.

Le processus DF et le processus analytique PFC de première génération ont fait l'objet d'un rapport

récemment. On a terminé l’élaboration du processus analytique PFC de deuxième génération qui était axée sur le développement du processus et des outils. Dans le présent document technique, on décrit brièvement le processus DF. On présente également un aperçu du processus analytique PFC de deuxième génération dans lequel on décrit les méthodes utilisées en précisant notamment comment elles se complètent et les améliorations apportées depuis la création du processus de première génération.

Executive summary

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Mark Rempel; DRDC CORA TM 2010-198; Defence R&D Canada – CORA; September 2010.

In 2005, the Canadian Forces' (CF) Chief of Defence Staff announced the commencement of the transformation of the CF. As with any complex organization, transformation of its structure and processes is not simple. However, success of such a transitions "depends upon leadership first identifying and understanding the thematic components of the past, and then, learning how to adapt and exploit the thematic strengths 'today' for the benefit of 'tomorrow' " [1]. While several themes have been identified within the CF transformation, one is in which the operational research community plays a vital support role is strategic decision-making.

In an effort to migrate the CF defence acquisition process towards one that is more proactive, a forward-looking decision-making process was developed: the Force Development (FD) process. The FD process, shown in Figure ES.1, employs Capability Based Planning (CBP), whose analytical process and associated tools provide decision-makers with an assessment of capability deficiencies, adequacies, and affluences. This assessment is central to the following defence acquisition trade-off analysis whose output is a cost-effective strategic capability roadmap, i.e., a plan describing CF capability development.

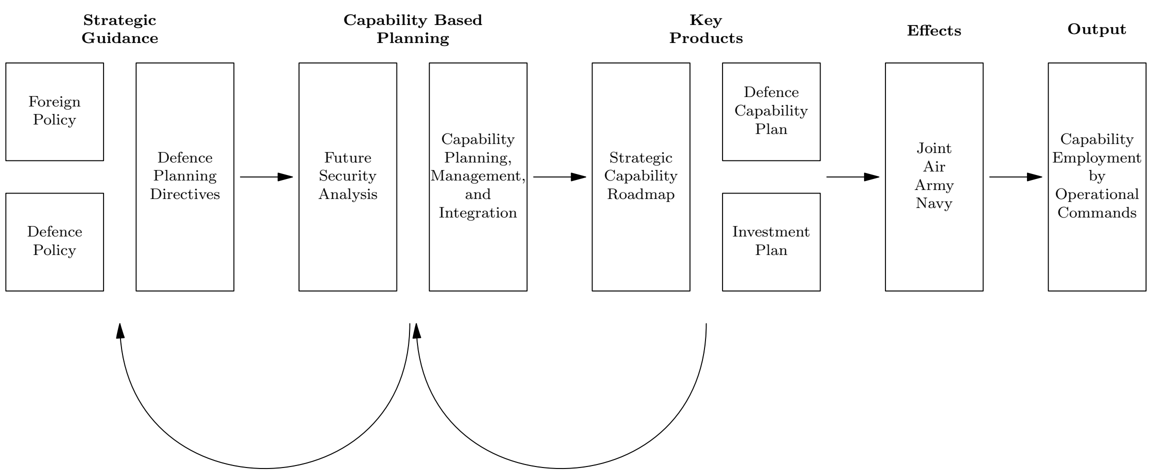

Figure ES.1: *Canadian Forces' force development process.*

At the core of CBP is the CBP analytical process, which is comprised of a set of soft and hard operational research methods that collectively implement the 'Capability Planning, Management, and Integration' component of CBP. The CBP analytical process, shown in Figure ES.2, is segmented into three sections, 'capability planning', 'capability management', and 'capability integration'. The process is comprised of inputs, analytical methods, subject matter expert analysis, and outputs that are represented in this figure by beveled boxes, rectangles with headers, rectangles, and

rounded rectangles respectively. While the five analytical methods, i.e., CATCAM, SC_2RAT, Concurrency, Optimization, Cost Sensitivity, have been modified as compared to their predecessors, e.g., CATCAM has been expanded to analyze an updated capability framework, SC_2RAT replaces and expands three previous methods, Concurrency was not previously included in the process, Optimization investigates the quality of its generated solutions, Cost Sensitivity employs a deterministic algorithm rather than a stochastic algorithm, the goal of the process has not changed; that is to generate a strategic capability roadmap.

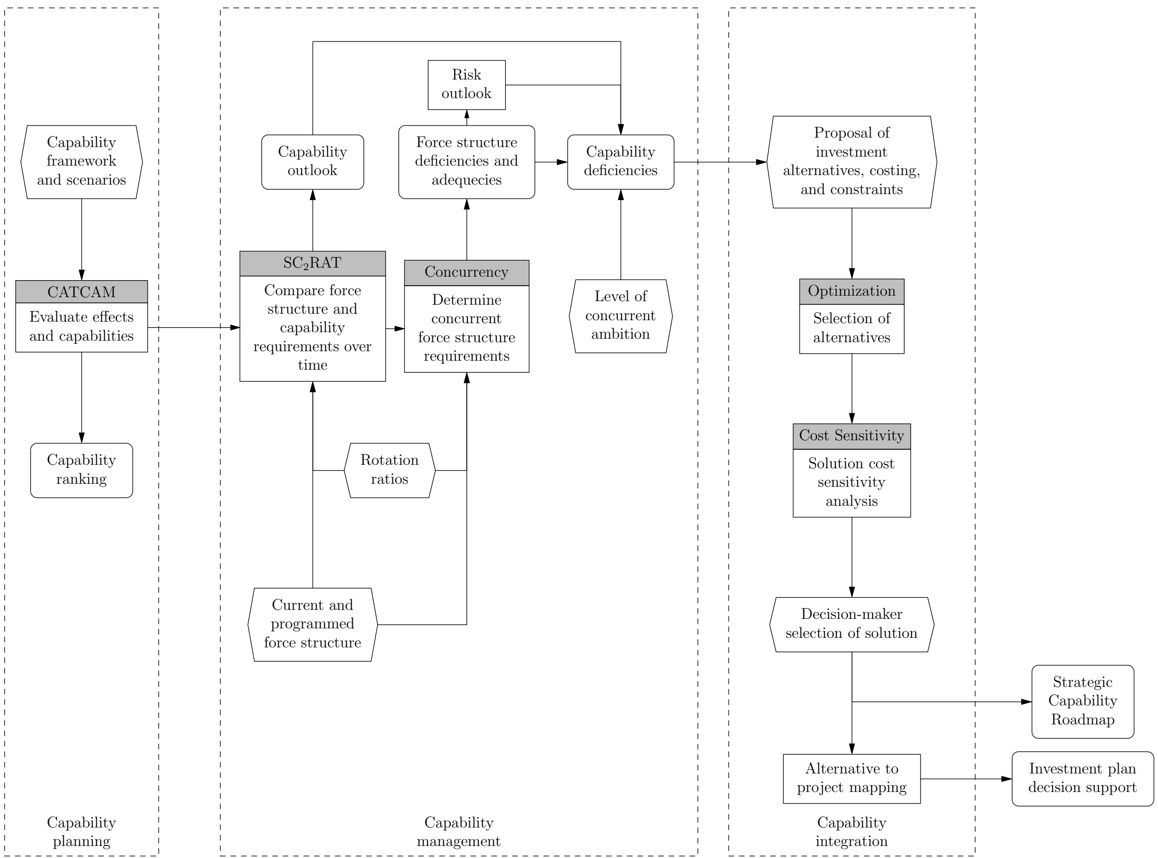

Figure ES.2: *Second generation CBP analytical process. Inputs are represented by beveled boxes, analytical methods are represented by rectangles with headers, subject matter expert analyses are represented by rectangles, and outputs are represented by rounded rectangles.*

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Mark Rempel ; DRDC CORA TM 2010-198 ; R & D pour la défense Canada – CARO ; septembre 2010.

En 2005, le Chef d'état-major de la Défense des Forces canadiennes (FC) a annoncé le début du processus de transformation des FC. Comme pour toute organisation complexe, la transformation de la structure et des processus n'est pas simple. Toutefois, pour assurer la réussite de cette transformation, « il faudra que les dirigeants déterminent et comprennent les éléments thématiques du passé et qu'ils apprennent à ensuite adapter et à exploiter les forces thématiques d'aujourd'hui afin de créer des occasions pour demain ». On a identifié plusieurs thàmes dans le cadre de la transformation des FC, dont celui de la prise de décisions stratégiques où la communauté de la recherche opérationnelle joue un rôle de soutien essentiel.

Dans l'optique de rendre le processus d'approvisionnement de la Défense des FC plus proactif, on a créé un processus rationnel de décision axé sur l'avenir : le processus de développement des forces (DF). Le processus DF, illustré au Figure Som.1, comprend la planification fondée sur les capacités (PFC), dont le processus analytique et les outils connexes offrent aux décideurs une évaluation objective des pénuries, des niveaux suffisants et des surplus en matière de capacités. Cette évaluation est essentielle pour effectuer une analyse des différentes options en matière d'approvisionnement pour la Défense et ensuite créer une feuille de route des capacités stratégiques rentables, c'est-à-dire un plan décrivant le développement des capacités des FC.

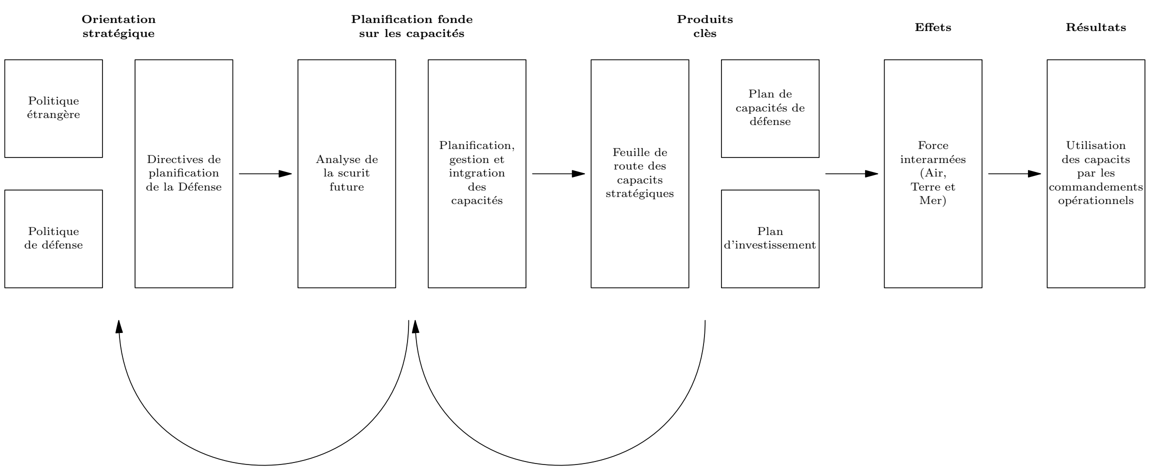

Figure Som.1: *Processus de développement des forces des FC.*

Le processus analytique PFC est au cœur de la planification fondée sur les capacités (PFC). Il comprend un ensemble de méthodes de recherche opérationnelle objectives et subjectives permettant la mise en œuvre du volet « planification, gestion et intégration des capacités » de la PFC. Le

processus analytique PFC décrit au Figure Som.2 se divise en trois sections : la planification des capacités, la gestion des capacités et l'intégration des capacités. Le processus comprend des intrants, des méthodes d'analyse, des analyses d'experts en la matière et des résultats qui sont représentés respectivement dans le tableau sous forme d'encadrés biseautés, de rectangles avec des en-têtes, de rectangles et de rectangles aux coins arrondis. Bien que l'on ait modifié les cinq méthodes d'analyse, à savoir l'EACMEC, la SC_2RAT, la concurrence, l'optimisation et l'élasticité du coût, le but du processus, c'est-à-dire créer une feuille de route des capacités stratégiques, demeure le même. L'EACMEC est maintenant plus importante pour permettre l'analyse d'un cadre des capacités actualisé, la SC_2RAT remplace et améliore trois méthodes, la concurrence a été intégrée au processus, l'optimisation permet d'évaluer la qualité des solutions proposées et on utilise maintenant un algorithme déterministe plutôt qu'un algorithme stochastique dans le cadre de la méthode de l'élasticité du coût.

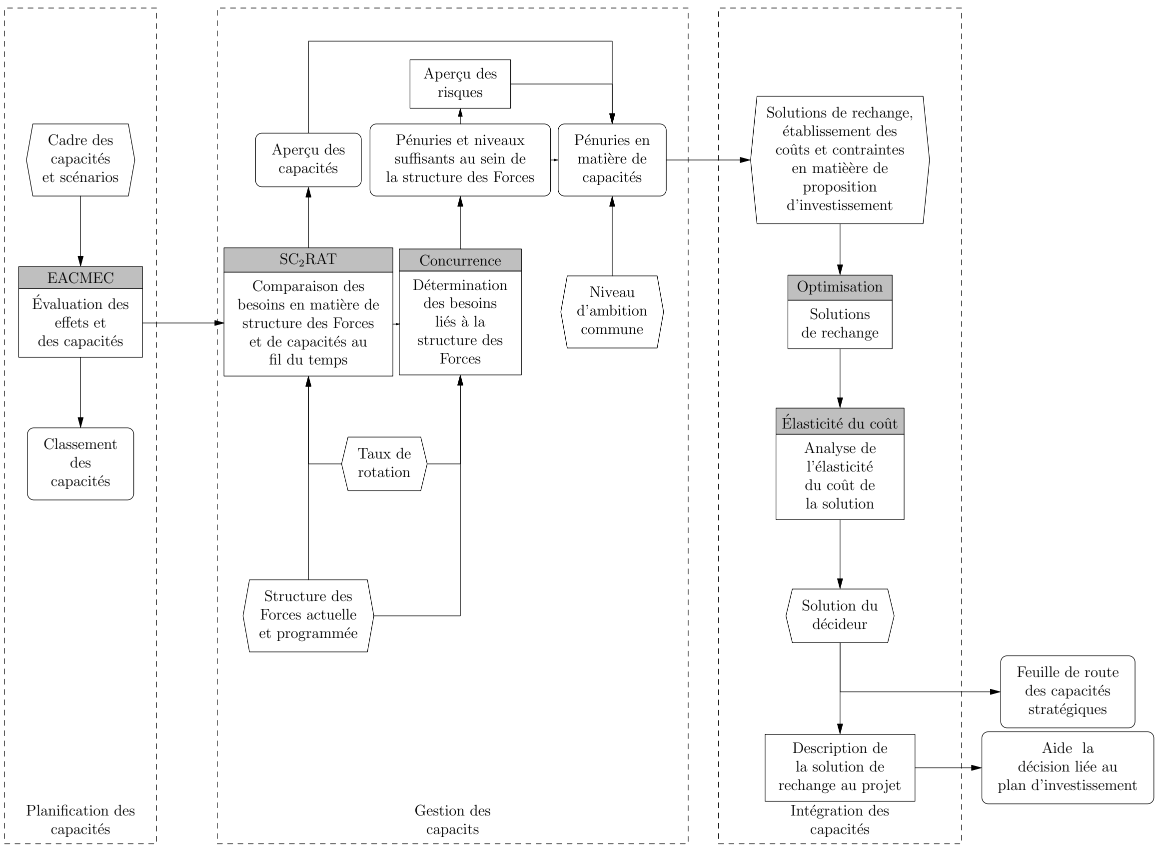

Figure Som.2: Processus analytique PFC de deuxième génération. Les encadrés biseautés représentent les intrants, les rectangles avec les en-têtes représentent les méthodes analytiques, les rectangles représentent les analyses des experts en la matière et les rectangles aux coins arrondis représentent les résultats.

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1 Introduction

1.1 Background

In 2005, the Canadian Forces' (CF) Chief of Defence Staff announced the commencement of the transformation of the CF. As with any complex organization, transformation of its structure and processes is not simple. However, success of such a transition "depends upon leadership first identifying and understanding the thematic components of the past, and then, learning how to adapt and exploit the thematic strengths 'today' for the benefit of 'tomorrow' " [1]. Several themes have been identified, such as civil-military relations, individualism, and strategic decision-making. Strategic decision-making, particularly in the context of defence acquisitions, is a theme in which the operational research community plays a vital support role.

Strategic decision-making for defence acquisitions has traditionally been a reactive process; that is basing equipment acquisitions on capabilities[1] that have been vital or unsatisfactory during previous CF missions [2]. This approach was previously sufficient, however is now deemed inadequate for various reasons, such as the diversity of military operations, e.g., domestic and continental operations, reacting to a major terrorist attack, supporting civilian authorities [3], and the importance of strong financial management practices, i.e., the Department of National Defence may only carry forward surplus funds equivalent to 1% of its yearly budget [4]. In response, the Department has migrated its strategic decision-making process for defence acquisitions from a reactive one to one that is more proactive: the Force Development (FD) process. At its core is Capability Based Planning (CBP) [5], which consists of two components: 'future security analysis' and 'capability planning, management, and integration'. The output of the 'future security analysis' component is a set of force planning scenarios that describe the future security environment, while the 'capability planning, management, and integration' component, which is implemented by an analytical process known as the CBP analytical process, uses the force planning scenarios to produce an assessment of the Department's defence capability deficiencies, adequacies, and affluences. This assessment is central to the following defence acquisition trade-off analysis, whose output is a cost effective strategic capability roadmap (SCR), i.e., a plan describing CF capability development. The SCR is key element in the transformation of the strategic decision-making in the CF.

1.2 Objective

The objective of this technical memorandum is to provide an overview of the second generation CBP analytical process[2], and discuss its methods and how they compare to the first generation methods. For a complete description of the first generation CBP analytical process, including its methods, the reader is referred to previous papers by Billyard and Blakeney [6], Blakeney *et. al.* [7, 8], Taylor *et. al.* [9], and Christopher *et. al.* [10]. As well, complete descriptions of each

[1] A capability may be defined as "A particular ability that contributes to the production of a desired effect in a given environment within a specified time and the sustainment of the effect for a designated period. Capability is delivered by an appropriate combination of PRICIE components" [2]. PRICIE refers to the functional components of a capability: Personnel/Leadership/Individual training, Research and Development/Operations Research, Infrastructure, Environment and Organization, Concepts, Doctrine, Collective Training, Information Management & Technology & Equipment Support.

[2] It should be noted that the first generation CBP analytical process was known as the SCR analytical framework. The name has been changed to emphasize the process rather than the output.

second generation CBP analytical method are published individually in existing, e.g., [11], or will be published in forthcoming Defence Research and Development Canada technical memoranda.

Three items should be noted with respect to the scope of this work. First, it is the purpose of this technical memorandum to present the state-of-the-art CBP analytical process and discuss its methods, rather than the results produced through executing the process. For information regarding the results of executing the CBP analytical process, the reader should contact the Directorate of Military Capability Management (see `http://cfd.mil.ca`). Second, the focus of the CBP analytical process presented is limited to the analysis of force employment capabilities, i.e., capabilities that are employed during operations. While the CF possess capabilities within the force generation and force development domains, these capabilities are not currently studied within the CBP analytical process. Third, CBP exists within the larger FD process, which in turn exists within the CF/DND strategic decision-making governance structure. While it is important to be cognisant of the governance structure, i.e., the results of the CBP process are utilized throughout the governance structure shown in Figure 1, it will not be discussed in this technical memorandum. For further information on the structure, the reader is referred to the Capability Based Planning handbook [2].

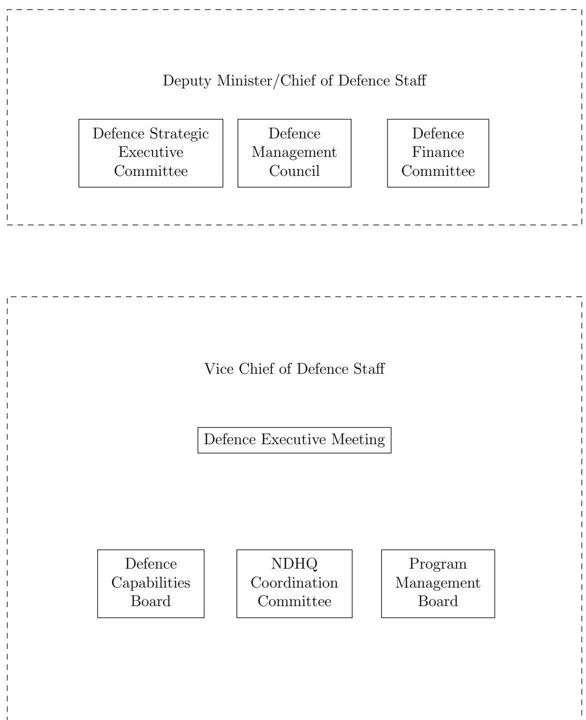

Figure 1: *CF/DND strategic decision-making governance structure. The lower four boards/committees are chaired by the Vice Chief of Defence Staff and the upper three committee/councils are co-chaired by the Deputy Minister and Chief of Defence Staff.*

1.3 Outline

The remainder of this technical memorandum is organized as follows: Section 2 presents an overview of the FD process, which is presented to provide a context for the CBP analytical process; Section 3 presents an overview of the second generation CBP analytical process and its methods, and highlights modifications of each method since the first generation; and Section 4 presents a conclusion.

2 Force Development Process

The strategic decision-making process for defence acquisitions is a key process within any modern military. The CF, in an effort to migrate its process towards a proactive one, has designed and implemented an end-to-end process that uses government strategic guidance as its input and as its output generates employable force elements[3] for the CF operational commands: the Force Development process. The FD process[4] is shown in Figure 2. While several feedback mechanisms exist within the process, two key loops are those between the 'Capability Based Planning' and 'Strategic Guidance' components and the 'Key Products' and 'Capability Based Planning' components. It should be noted that the SCR, which is envisioned as a key element for transformation of strategic decision-making within the CF, exists within the 'Key Products' segment and is a product of the 'Capability Based Planning' component.

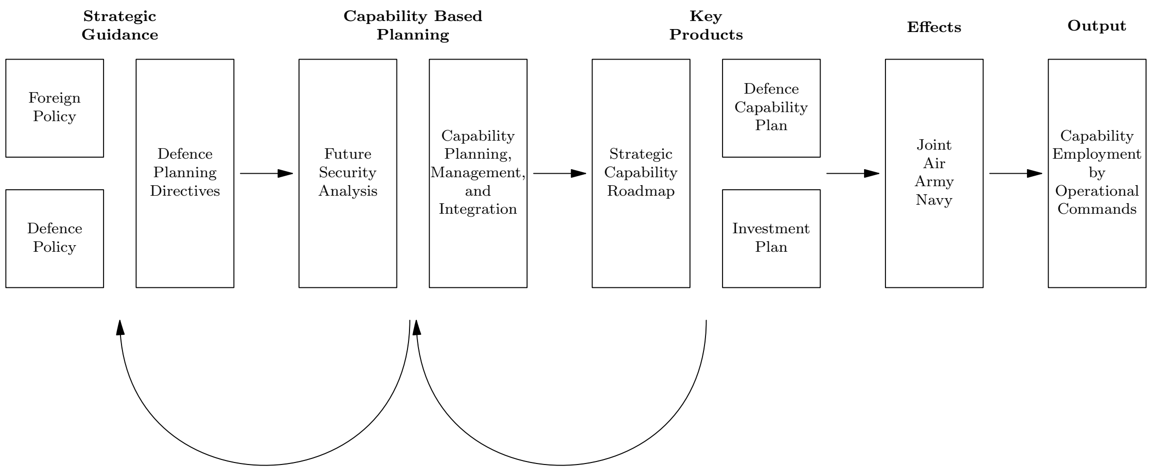

Figure 2: *Canadian Forces' force development process.*

The FD process begins with an assessment of strategic guidance, such as foreign and defence policy, e.g., Canada First Defence Strategy [3], and defence directives from senior military and civilian leadership. This guidance, which describes current and future defence and security priorities, forms the input to the CBP component.

The CBP component is split into two segments: 'future security analysis' and 'capability planning, management, and integration'. The 'future security analysis' segment evaluates the future security environment and generates force planning scenarios[5] that represent operations the CF is likely to be engaged in given the strategic guidance. In conjunction with the force planning scenarios, there exists a capability framework that describes the full spectrum of military capabilities that the CF either has, may have in the future, or neither but are required by the scenarios. The force planning

[3] A force element is defined as a fundamental unit within the CF that can be utilized to provide capability within an operation. The unit may perform a tactical, operational, or strategic level function [10]. Examples of force elements are one CC-177, one fixed-wing search and rescue aircraft, or one engineer field squadron.

[4] The CF FD process is a waterfall model, i.e., sequential development process, with feedback.

[5] The force planning scenarios depict a range of domestic, continental, and international events and possibilities across the full spectrum of conflict [2].

scenarios and capability framework, which provides a common language to discuss CF capabilities, form the input to the 'capability planning, management, and integration' component.

The 'capability planning, management, and integration' segment, which is the analytical engine of CBP, is further divided into three elements: 'capability planning', 'capability management', and 'capability integration'. The 'capability planning' component describes the capability framework elements[6] that the force planning scenarios require. This process begins with an evaluation of standardized effects[7] within each scenario. Subsequently, the capability framework elements are evaluated to determine if they are able to create each effect. Along with the evaluation, a set of questions, known as measures of capability, are created for each capability framework element. The purpose of the measures of capability is to further quantify and qualify the role of the element within the scenario.

The 'capability management' component, which is the follow-on process to 'capability planning', determines how the CF will provide the aforementioned capability framework elements within each scenario. The process begins by comparing the capability framework element requirements with existing and programmed operational force elements over time for each scenario and subsequently assigning force elements to framework elements. The scenarios' force element requirements are combined together to form concurrent scenario force element requirements. This information is summarized in two interim results, a capability outlook and a risk outlook. The capability outlook provides a high-level view of the potential of the existing and programmed operational force elements to achieve individual scenario capability framework element requirements over time. The risk outlook provides a view of the operational risk to the success of a scenario, and combination of scenarios, i.e., concurrent scenarios. These two interim outputs provide the basis for the determination of the set of CF capability deficiencies, which are those capability framework elements that do not have adequate force elements assigned.

While the capability and risk outlooks aid the understanding of the capability deficiencies, they do not provide insight into how to address them. This is performed in the 'capability integration', i.e., integration of alternatives to address capability deficiencies with the existing investment plan, component through a three step procedure: determination of alternatives[8] to address each deficiency; selection of a set of alternatives; and review/approval of selected alternatives by decision-makers. The set of approved alternatives for the deficiencies analyzed are one of the key inputs to the SCR.

The key products of the FD process are: SCR, investment plan, and the defence plan. The SCR, which is the direct output of the CBP component, is the aforementioned list of approved alternatives as well as government approved initiatives, e.g., as extracted from the Canada First Defence Strategy [3]. The alternatives are ranked based on a variety of metrics, such as cost, military value, and personnel requirements. As well, each alternative and government initiative is mapped to a set of tangible projects. These projects, along with a proposed implementation schedule, form the input

[6] The capability framework is a hierarchical structure and each level is comprised of a set of elements. A level within the capability framework, e.g., level 4, is selected to perform the analysis throughout the analytical process.

[7] An effect is defined s a physical, functional, or psychological outcome, event, or consequence that results from the execution of specific tasks [2].

[8] Alternatives are options to address capability deficiencies, such as the purchase of equipment, addition of personnel, or research and development projects.

to the investment plan. The final key product, the defence plan, is a business plan that provides defence tasks and resource allocation. It is primarily a management tool that integrates priorities, vision, and policy.

The key products described above articulate the required capabilities of the CF and how to address them, however they are not the final output. The measurable effects, which are those created by the Army, Navy, and Air Force, as well as the generated employable force elements are the final output of the system, i.e., force development, force generation, force employment, as a whole. It is these effects that determine the overall success, or failure, of the system.

The feed forward path, i.e., strategic guidance $\rightarrow$ capability based planning $\rightarrow \ldots$, is the primary path in the FD process; however, the feedback paths play an important role as well. The role of the feedback paths is to provide the ability to apply corrective action, e.g., modifying strategic guidance, removal of a capability deficiency, within the FD process. For example, the feedback path between 'capability based planning' and 'strategic guidance' recognizes that the capability based planning process may influence the strategic direction provided by the government. As well, the feedback path between the 'key products' and 'capability based panning' recognizes that the investment plan is not static, due to changing project timelines and funding, and subsequently impacts the selection of alternatives to address capability deficiencies.

3 Capability Based Planning Analytical Process

The core of the FD process, as described in the previous section, is CBP. The CBP component, which is further divided into 'future security analysis' and 'capability planning, management, and integration', transforms its inputs, i.e., foreign policy, defence policy, into a capability roadmap through applying soft, e.g., subjective analysis of effects and capability framework elements in scenarios, and hard, e.g., optimization of alternatives to address capability deficiencies, operational research techniques. The 'capability planning, management, and integration component' is the analytical engine of CBP and is implemented through the CBP analytical process. The second generation CBP analytical process is based on its predecessor [8, 9, 10], which in turn is based on the generic process proposed by The Technical Cooperation Program Joint Systems and Analysis Group Technical Panel 3 [12] and Burton *et. al.* [13]. While similar to previous work, the second generation introduces new methods and modifications to existing methods.

3.1 Overview

The CBP analytical process is comprised of a set of soft and hard operational research methods that collectively implement the second component of CBP, which is 'capability planning, management, and integration'. The process, shown in Figure 3, is segmented into three sections, 'capability planning', 'capability management', and 'capability integration'. The process is comprised of inputs, analytical methods, subject matter expert analysis, and outputs that are represented in this figure by beveled boxes, rectangles with headers, rectangles, and rounded rectangles respectively. There are five analytical methods, i.e., CATCAM, SC_2,RAT, Concurrency, Optimization, and Cost Sensitivity, and two subject matter expert analyses, i.e., risk outlook and alternative to project mapping. Each method within the process is either new, modified, or has been further investigated as compared to the first generation methods. The second generation modifications to the analytical methods are summarized as follows:

- CATCAM has the ability to analyze multiple levels within the capability framework;
- SC_2RAT replaces three first generation methods;
- Concurrency is new and did not exist in the first generation;
- Optimization has been further investigated to gauge the quality of its generation solutions; and
- Cost Sensitivity has been modified to employ a deterministic algorithm rather than one that is stochastic.

The remainder of Section 3 provides an overview of each analytical method, including their inputs, outputs, and modifications since the previous generation. The risk outlook is discussed in the Concurrency section and alternative to project mapping is discussed in the Cost Sensitivity section.

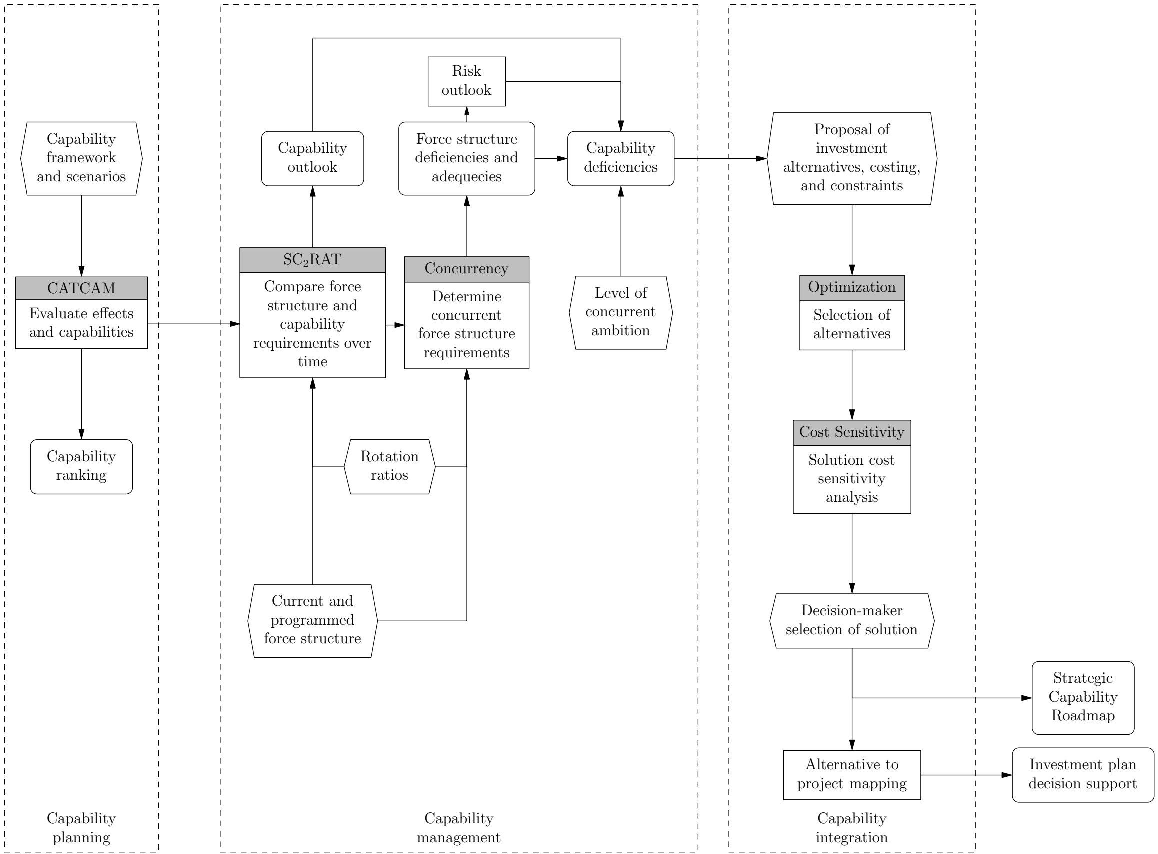

Figure 3: *Second generation CBP analytical process. Inputs are represented by beveled boxes, analytical methods are represented by rectangles with headers, subject matter expert analyses are represented by rectangles, and outputs are represented by rounded rectangles.*

3.2 CATCAM

CATCAM [6, 14], that is the Chief of Defence Staff Action Team 3 Capability Assessment Methodology, is a key operational research tool in the CBP analytical process. Its primary purpose is to evaluate and prioritize the capability framework elements within force planning scenarios. The capability framework is a hierarchical structure, where each level is comprised of a set of elements and each successive lower level provides a greater degree of fidelity, i.e., an element in level 1 of the structure may be divided into three elements in level 2, and each may be further divided in level 3. An example segment of the capability framework is shown in Figure 4, where the levels are labeled as ‘Domain’, ‘Capability’, ‘Function’, ‘Activity’, and ‘Subactivity’.

The analysis performed using CATCAM begins by subject matter experts assessing each of six standardized mission effects, i.e., control, shape, stabilize, shield, project and sustain, and informed direction [2], with respect to their required frequency and the consequence if the effect is not created within each scenario. Subsequently, subject matter experts assess the capability framework elements that are required to create the effects through the elements’ required frequency and the consequence

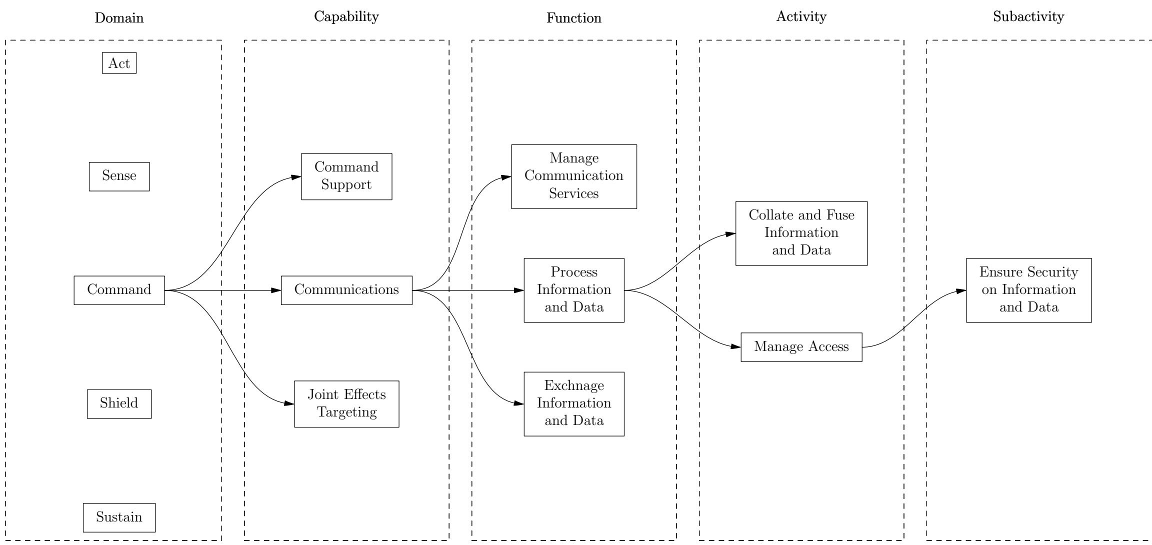

Figure 4: *Capability framework example.*

if the elements can not create the effects[9]. For example, Figure 5 shows a segment of the CATCAM method in which the 'Control' effect is assessed to have a high frequency and high consequence, i.e., as indicated by an 'hh' for high frequency and high consequence under the 'Control' effect, and the 'Deny Portions of the Sea' framework element is assessed to have a low frequency and medium consequence with respect to the 'Control' effect, i.e., as indicated by a 'lm' for low frequency and medium consequence, for the given scenario. The assessments are converted into numerical scores, and an overall score for each capability framework element across the effects is calculated using a weighted sum[10] based on normalized mission effect scores [6]. The set of numerical scores[11], as described by Billyard and Blakeney [6], for each scenario is passed between the 'capability planning' and 'capability management' components. As well, a set of questions, known as measures of capability, are provided with each assessment. The purpose of the measures of capability is to further quantify and qualify the role of the capability framework elements throughout the scenarios.

The algorithms within the second generation CATCAM tool are similar to those employed in the first generation; however, modifications were made to accommodate for an extended capability framework. Whereas the first generation capability framework consisted of four levels, i.e., Domain → Capability → Function → Activity, the second generation capability framework included a fifth level, i.e., Subactivity, in order to provide a greater degree of fidelity throughout the CBP analytical process. In order to accommodate the fifth level, and allow a comparison with first generation results, i.e., the Activity level of the capability framework was assessed in the first generation, the capability framework element assessments were performed in two stages. The elements in the Activity level were evaluated in an identical manner as to those in the first generation. However,

[9] It should be noted that capability framework elements can be labeled as 'enablers'; that is, they do not deliver an effect themselves, rather they enable other framework elements to deliver an effect [14].

[10] It should be noted that the calculation assumes that the effects are orthogonal; that is the evaluation of one effect does not influence the evaluation of a second effect.

[11] The numerical scores may be used to create a prioritized list of capabilities for each scenario.

Capability	Functions	Activities	Effect Control	Effect Shape	Effect Stabilize
			hh	hm	ml
Maritime Effects Production	Deny Maritime battlespace to OPFOR	Defeat OPFOR Maritime Platforms	mh	mm	
		Deny Portions of the Sea	lm	ll	
	Provide freedom of manoeuvre in Maritime battlespace	Combine forces for operations			hh
		Control Sea Lines of Communication	mm	mh	
		Defeat or avoid OPFOR Maritime mines	ll	lm	
		Control Merchant shipping			mm
		Conduct coastal security		ll	

Figure 5: *Example segment of CATCAM with sample data.*

the elements in the Subactivitiy level were evaluated with respect to their associated Activity level elements rather than the effects, i.e., the frequency with which the Subactivity is required to perform the Activity and the consequence the Activity can not be performed if the Subactivity can not be performed. The Subactivity scores were computed in a similar manner to the Activity scores, however rather than being weighted by the effects they were weighted by their associated Activity. Thus, the 'capability planning' component of the CBP analytical process passed Activity and Subactivity scores to the 'capability management' component.

3.3 SC$_2$RAT

The Scenario Capability/Capacity Requirements Assessment and Outlook Tool (SC$_2$RAT) is the follow-on method to CATCAM. SC$_2$RAT, which uses the capability framework element scores determined in CATCAM, existing and future programmed operational force structure, and force element rotation ratios as input, generates a capability outlook that effectively describes the health of the CF capabilities over time for each force planning scenario. This is accomplished through a three step procedure: first, subject matter experts evaluate the types and number of force elements required to perform the Subactivities[12]; second, operational force elements are assigned to Subactivities based upon a set of rules, e.g., force elements are assigned to higher ranked Subactivities first; and third, generation of a capability outlook for each scenario, which is a summary of the capability adequacies and deficiencies. The first and second steps are required for each time period studied where there is a change in the operational force structure.

An example of a segment of SC$_2$RAT for a single scenario and time period is shown in Figure 6. The capability framework and the Subactivity scores are shown in the left portion of the tool and across

[12] Any capability framework level could be analyzed, however the second generation CBP analytical process used the Subactivity level as described in Section 3.2.

the top is the required scenario information, i.e., duration, rotation length, and the force structure, i.e., force element types, quantity, rotation ratio, for the given time period. The lower right portion provides the ability for subject matter experts to perform the first step in the procedure; that is, to evaluate the type and number of force elements required for each Subactivity. There are two types of evaluations: primary and secondary. A primary evaluation is the number of force elements of a type required from those available in the force structure for a single rotation to perform a Subactivity. A secondary evaluation is similar to a primary evaluation, however rather than requiring the force elements from the force structure the force elements are required from an identified primary evaluation. The purpose of the secondary evaluation is to allow the tool to reflect the reality that a set of force elements may perform more than one subactivity. As a guide to the evaluations, the measures of capability provided from CATCAM are used to assist the subject matter experts during the evaluations. As an example, 'Conduct CANUS initial planning' is a primary evaluation that requires two force elements of type FE1 and 'Conduct strategic and operational' is a secondary evaluation, i.e., linked to Subactivity 1.1.1.1.4, that requires one force element of type FE1. The number of force elements required for a secondary evaluation must be less than or equal to that in the associated primary evaluation.

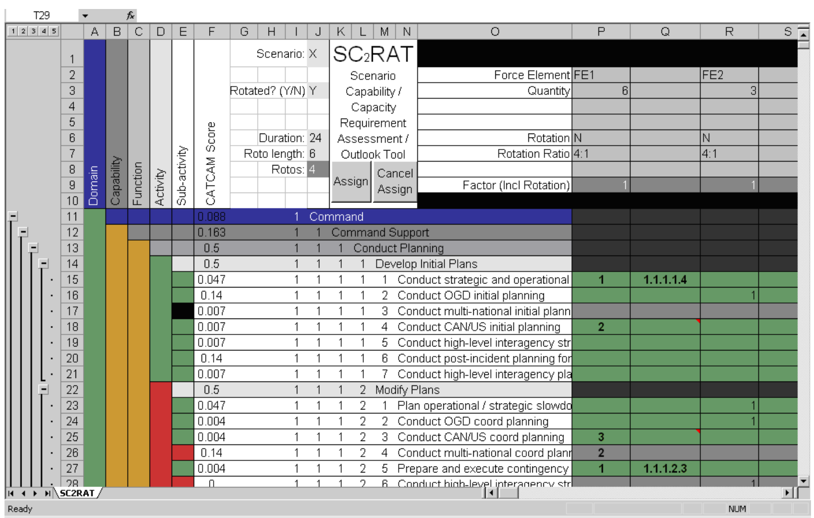

Figure 6: *Example segment of SC$_2$RAT with sample data for a single scenario and single time period. The segment does not show the entire capability framework or force element set for the time period.*

The second step in the procedure, which is the assignment of force elements to Subactivities, is performed after all Subactivities have been evaluated by subject matter experts. The assignment heuristic assigns force elements to Subactivities based on their score, i.e., greedy algorithm; that is, force elements are assigned to the Subactivities with the highest CATCAM score with a primary evaluation first, the second highest CATCAM score with a primary evaluation second, and so forth. During each assignment the number of required force elements is checked against the force structure; if there are enough force elements available, then the number required is removed from

those available and the Subactivity is labeled green[13], i.e., adequate capability, else if there are not enough force elements available the Subactivity is labeled red, i.e., deficient capability, and the required force elements are not removed from those available. This assignment heuristic is repeated for each Subactivity, however once a Subactivity is labeled red further force element assignments are not performed for that Subactivity. It should be noted that all the force elements required for a Subactivity must be available and assigned for the Subactivity to be labeled green; however, the lack of a single force element will cause the Subactivity to be labeled red. The secondary evaluations are not assessed in the assignment heuristic, and thus are assessed to be green.

The final step of the procedure is the generation of a capability outlook for each scenario. An example is shown in Figure 7. The outlook for each year for each Subactivity is taken directly from SC_2RAT, and these are subsequently aggregated to higher-levels in the capability framework. The aggregation algorithm is based on degradation, i.e., a combination of geometric and additive aggregation techniques are employed, caused by lower level deficiencies, and each aggregation is assigned a color, i.e., red, yellow, green, based on the degree of degradation, i.e., Subactivity 1.1.1.6 degrades Activity 1.1.1 sufficiently that is is deemed a deficiency in 2009.

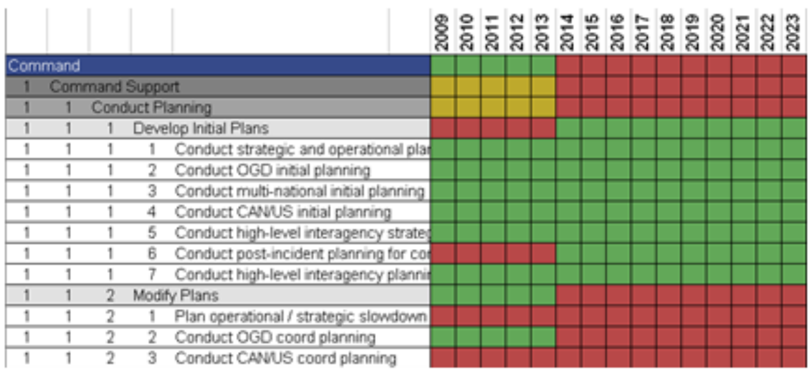

Figure 7: *Example segment of the capability outlook.*

SC_2RAT effectively replaces three methods from the first generation CBP analytical process: the Force Generation and Evaluation (FoRGE) tool [7, 10], the Capability Outlook Tool [15], and the Activity-Based Neoteric Deficiency Ranking and Evaluation Workbook (ANDREW) [10]. FoRGE provided a similar construct as SC_2RAT for evaluating the set of force elements that could provide a given capability. However, rather than a specific number of force elements, FoRGE simply allowed subject matter experts to indicate if a force element could or could not provide a given capability framework element. While FoRGE identified which force elements could be utilized, it did not account for the capacity of force elements required as SC_2RAT does. Following this analysis, the Capability Outlook Tool transformed the data collected from FoRGE into a capability outlook, similar to the output generated by SC_2RAT as shown in Figure 7. Using the capability outlook, in a similar method as to that used in the second generation, subject matter experts created a list of capability deficiencies. ANDREW was then used to prioritize the deficiencies, based on their level of impact to perform the capability framework elements in the scenarios. This assessment is now provided through the degradation calculations in SC_2RAT.

[13] See column E in Figure 6.

3.4 Concurrency

While SC_2RAT investigates the force element requirements of individual scenarios, and subsequently the health of the required capability framework elements through the capability outlook, it does not investigate the force element requirements of concurrent scenarios. The Concurrency method [11] provides this insight through assessing the force element requirements of concurrent scenarios and comparing those to the current and programmed force structure. This is done through a three step process: first, calculation of the total force elements required, including rotations, for each scenario; second, calculation of the force elements required for combinations of scenarios; and third, determination of force element deficiencies and affluences as a function of scenario concurrency and risk tolerance. There are three levels of risk tolerance that affect the force elements required for a set of concurrent scenarios. The three levels are as follows:

- 'No risk': the required force elements are the sum of the scenario requirements, including rotations, i.e., if scenario i requires three force elements of type x with a 4:1 rotation ratio and scenario j requires two force elements of type x with a 3:1 rotation ratio, the total number of force elements of type x required for scenario i and j concurrently is $3 \cdot (4+1) + 2 \cdot (3+1) = 23$;
- 'Force Generation (low) risk': the required force elements are the sum of the scenario requirements, however this may be reduced by employing rotations from a scenario within another scenario[14], i.e., if scenario i requires three force elements of type x with a 4:1 rotation ratio and scenario j requires two force elements of type x with a 3:1 rotation ratio, scenario j may employ two[15] rotations from scenario i, thus reducing the total number of force elements required to 17 ($23 - 3 \cdot 2 = 17$); and
- 'Force Generation and Operational (medium) risk': the required force elements are the sum of the scenario requirements, however this may be reduced by employing rotations in a similar fashion to the 'Force Generation risk' assumptions, although with fewer restrictions[16].

The concurrent force element requirements within a single time period are summarized as force structure deficiencies and adequacies, for various scenario combinations and risk levels, as shown in Figure 8. This example shows the three risk levels for four combinations of scenarios, where each combination of scenarios show three rows: the top row represents 'No risk' , the middle row represents 'Low risk', and the bottom row represents 'Medium risk'. For each risk level/concurrent scenario combination the green region represents the percentage of force elements that are able to meet the concurrent demands, the red region represents the percentage that are no able to meet the concurrent demands, and the yellow region shows the percentage that transition from red to green through incurring a given level of risk. As an example, the percentage of force elements that are not

[14]It should be noted that currently only the 'Baseline' scenario, i.e., daily domestic CF responsibilities, may employ rotations from another scenario at the 'Force Generation risk' level. For more information, the reader should consult Pelletier [11].

[15]It should be noted that at least one rotation must not be employed, e.g., a 4:1 rotation ratio may provide up to two force elements rotations, a 3:1 rotation ratio may provide up to one force element rotation.

[16]Whereas the 'Force Generation risk' level may only employ rotations from other scenarios in the 'Baseline' scenario, the 'Force Generation and Operational risk' may employ 'Baseline' scenario rotations in 'Domestic/Continental' scenarios or non-rotated 'International' scenarios.

able to meet the concurrent demands for the lower combination of three scenarios given ‘No risk’ is approximately 28%. This output is used by subject matter experts to create the risk outlook [10], which describes the risk of the CF not being able to create the concurrent mission effects over time. An example of a risk outlook is shown in Figure 9, where red means that there is a high likelihood of failure, yellow means that there is a chance of failure, and green means that failure is unlikely. The numbers across the top of the figure represent the time period, i.e., year. It should be noted that the risk outlook assumes the ‘No risk’ risk tolerance level.

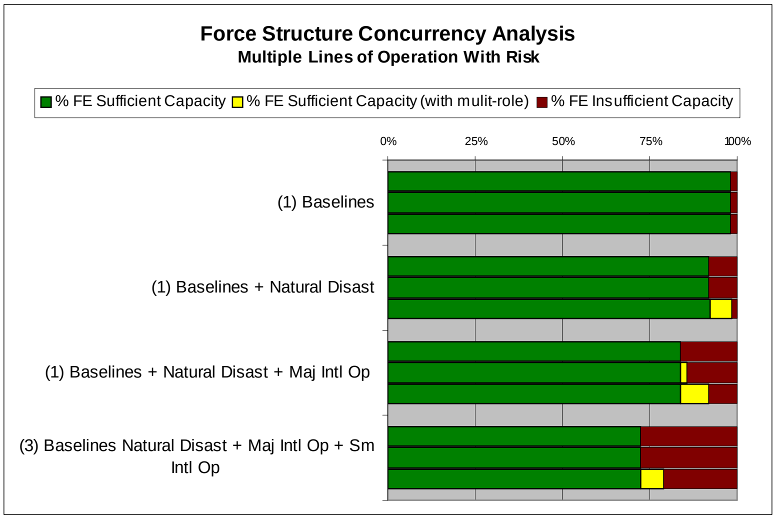

Figure 8: *Example of force element deficiencies and adequacies in concurrent scenarios.*

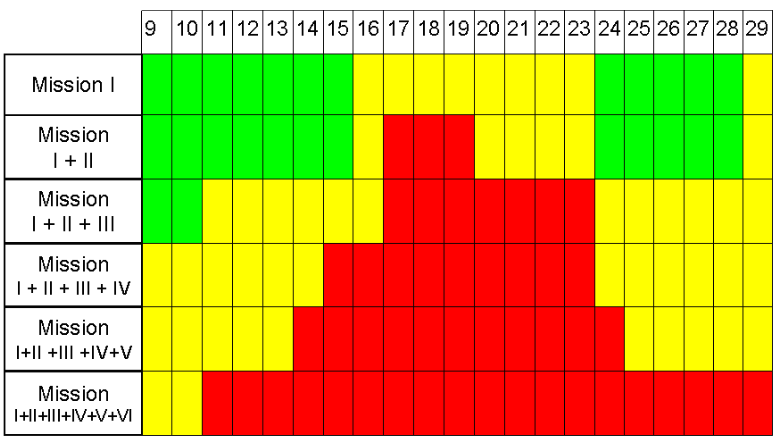

Figure 9: *Example of the risk outlook.*

The Concurrency method was not included in the first generation analytical process. While it has long been recognized that concurrency analysis is an important element of the CBP analytical process [13], due to aggressive timelines and resource constraints the concurrency method was not developed until the second generation. For more information regarding the Concurrency method see [11] and regarding the risk outlook see [10].

3.5 Optimization

The optimization component of the CBP analytical process provides the ability to search the solution space for non-dominated sets[17] of solutions that best address the identified capability deficiencies, where a solution is comprised of a set of capability investment alternatives [9, 10]. The capability investment alternatives are described by a variety of parameters, however the parameters employed in the optimization are as follows[18]: degree to which the alternative addresses its capability deficiency; equivalent annual cost[19]; personnel requirements; and dependencies on other deficiencies and alternatives. Thus, the objective of the optimization is to determine non-dominated solutions that provide maximum military value for minimum equivalent annual cost, where military value of an individual alternative is based on the importance of the capability deficiency it addresses, i.e., the importance is related to the CATCAM scores of the capability framework elements that the deficiency represents, the alternative's ability to address its capability deficiency, and the presence of other specified deficiencies and alternatives in the solution. As well, the feasibility of a solution is limited by a set of constraints, primarily the number of military personnel required. As a result of the dependencies between alternatives in a solution, the objective function for the military value is modeled by a nonlinear equation, and thus a heuristic is used to determine the non-dominated set of solutions.

As with any heuristic, the non-dominated set found is not guaranteed to be the Pareto-optimal set[20]. An example of a non-dominated and Pareto front, i.e., the solutions of each set exist on their respective fronts, are shown in Figure 10. As such, without a guaranteed upper bound on military value as a function of cost, there is no indication as to the quality of the non-dominated solutions. While the heuristic employed, i.e., constrained multi-objective genetic algorithm[21] in the second generation has not been modified as compared to its first generation implementation, the quality of the solutions generated have been investigated. Three avenues were undertaken: generation of solutions using a constrained single objective genetic algorithm, evaluation of the algorithmic parameters, e.g., population size, mutation rate, of the multi-objective genetic algorithms to determine their effect on the algorithm's efficacy, and comparison with solutions determined using a second single objective heuristic based on an iterated local search. With respect to the first items, the constrained multi-objective genetic algorithm was converted into a constrained single objective genetic algorithm, such that cost was a constraint rather than an objective. The cost constraint was set at various values and the determined solutions were compared to those found using the constrained multi-objective genetic algorithm. As well, the solutions were used to seed the initial population of the constrained multi-objective genetic algorithm in an effort to direct it towards a feasible region

[17] Among a set of solution $\mathbf{P}$, the non-dominated set of solutions $\mathbf{P}'$ are those that are not dominated by any member of the set $\mathbf{P}$ [16]. When comparing two solutions $p^{(1)}$ and $p^{(2)}$, $p^{(1)}$ is said to dominate $p^{(2)}$ if it is no worse in all objectives and it is better in at least one objective.

[18] Parameters other than those in the list are collected, such as risk, e.g., technology, implementation, and accuracy of cost.

[19] The equivalent annual cost of a capability investment alternative includes several factors, such as acquisition cost, military and civilian personnel salaries, indirect cost for procurement, operations and maintenance, equipment support, basing, and research and development [10].

[20] The non-dominated set of the entire feasible search space S is the globally Pareto-optimal set [16].

[21] The genetic algorithm was implemented using the Phoenix Integration Software - see `http://www.phoenix-int.com/`.

quickly and reduce computational time[22]. Through these three avenues the following was determined: the constrained single objective heuristic generated solutions comparable to the constrained multi-objective genetic algorithm; injection of good solutions in the initial population decreased the computational time of the constrained multi-objective genetic algorithm, however this did not result in dramatically better solutions; the efficacy of the algorithm was not significantly affected by the choice of parameters; and the second single objective heuristic generated comparable solutions to the constrained multi-objective genetic algorithm. Thus, while the Pareto set was not determined, the confidence in the quality of the solutions has been increased.

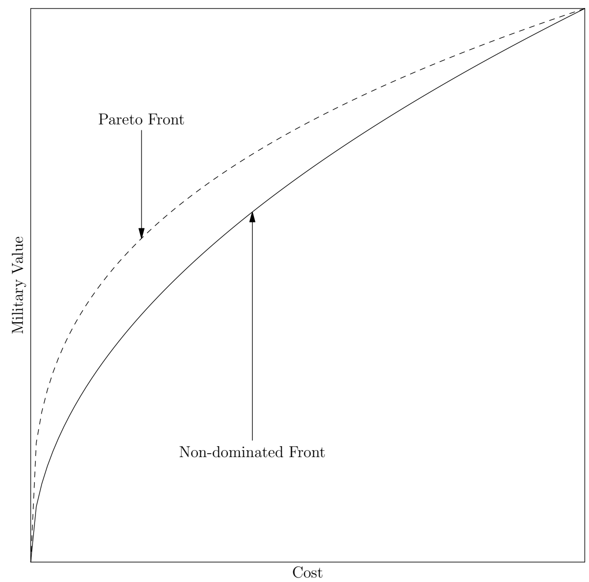

Figure 10: *Example of a non-dominated from and a Pareto front.*

3.6 Cost Sensitivity

While the optimization component of the CBP analytical process determines non-dominated solutions, i.e., sets of capability investment alternatives, at various equivalent annual costs, it does not investigate the risk of delivering the solutions due to cost risk. This is accomplished through a follow-on process: cost sensitivity. Given that the equivalent annual cost of each capability investment alternative exists within a distribution, i.e., the lower and upper bounds of the equivalent annual costs provided for each alternative are assumed to form a triangular distribution, this information may be utilized to provide further insight into the cost risk of each solution, such as the probability that a solution will not exceed a given funding limit, i.e., solution x has an equivalent annual cost c, however there is a probability p that the cost will not exceed a cost of k. An example of this type of analysis is shown in Figure 11[23], where the triangles (yellow line) represent the percentage of maximum military value delivered, i.e., the non-dominated solutions in Figure 10, and

[22] A single run of the first generation constrained multi-objective genetic algorithm required approximately 24 hours to perform a single run.

[23] This figure was provided by Mr. Leonard Kerzner.

the squares (purple line) represent the probability that the non-dominated solution is achievable for a given funding limit. While other types of analyses exist within the cost sensitivity component, the analysis shown in Figure 11 is representative of the type of information obtained from the cost sensitivity analysis.

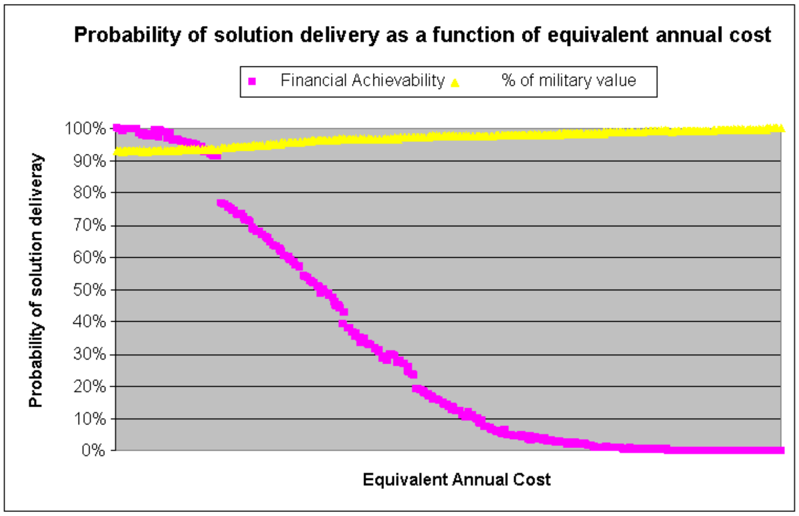

Figure 11: *Probability of solution delivery as a function of equivalent annual cost given a funding limit.*

The information generated through the cost sensitivity analysis aids decision-makers in selecting a solution from those determined through the optimization process. The selected solution, subject to changes by decision-makers, i.e., due to strategic or political guidance, is the approved set of capability investment alternatives and is one of the key inputs to the SCR. Following the approval of the solution, each alternative is mapped to a set of tangible projects. These projects, rather than the capability investment alternatives, form a portion of the input to the investment plan.

The purpose of the cost sensitivity component within the CBP analytical process was not altered between the first and second generation, however the implementation of the component was changed. Cost sensitivity in the first generation was performed using a Monte Carlo simulation [10], where the approximation of the cost distribution of a solution was determined through sampling the cost distributions of its alternatives. While this is a valid method to perform this type of analysis, the second generation employed the mathematical properties of the capability investment alternatives' triangular distribution within a solution and curve fitting to calculate its approximate cost distribution. The primary difference between these two approaches is that the first generation method employs a stochastic algorithm, while the second generation method employs a deterministic algorithm.

4 Conclusion

In this technical memorandum the second generation CBP analytical process, which exists within the CF FD process, was presented. An overview of each method within the process was discussed with an emphasis on how the methods work together and their modifications since the first generation. The second generation operational research tools, their objective, inputs and outputs, and summary of modifications since the first generation are summarized in Table 1.

Table 1: *Summary of CBP analytical process methods.*

Method	Objective	Inputs	Outputs	Modifications
CATCAM	Evaluate and prioritize capability framework elements within force planning scenarios.	Capability framework, scenario effects' weighting	Prioritized capability framework elements for each scenario	Ability to analyze Activity and Subactivity capability framework levels.
SC_2RAT	Assign force elements to capabilities and generate capability outlook for each scenario	Prioritized capability framework, force elements, rotation ratios	Required force elements and capability outlook for each scenario	Replaces FoRGE, Capability Outlook tool, and ANDREW
Concurrency	Determine force element requirements for concurrent scenarios and force structure deficiencies and adequacies	Required force elements for each scenario, rotation ratios	Force structure deficiencies and adequacies	Not included in previous generation
Optimization	Determine sets of non-dominated investment alternatives that maximize the closure of force structure deficiencies and minimize cost	Investment alternatives and constraints	Non-dominated sets of investment alternatives	No modifications to the optimization algorithm itself, however the quality of solutions has been investigated
Cost Sensitivity	Determine risk of delivering non-dominated solutions due to cost risk	Non-dominated solutions, lower and upper cost bounds for each investment alternative	Probability of solution delivery for varying cost	Deterministic algorithm to determine cost distributions rather than a stochastic algorithm

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List of abbreviations

ANDREW	Activity-Based Neoteric Deficiency Ranking and Evaluation Workbook
CATCAM	Chief of Defence Staff Action Team 3 Capability Assessment Methodology
CBP	Capability Based Planning
CF	Canadian Forces
DND	Department of National Defence
DRDC	Defence Research and Development
FoRGE	Force Generation and Evaluation
FD	Force Development
GA	Genetic Algorithm
PRICIE	Personnel/Leadership/Individual training, Research and Development/Operational Research, Infrastructure, Environment and Organization, Concepts, Doctrine, Collective Training, Information Management & Technology & Equipment Support
SC_2RAT	Scenario Capability/Capacity Requirements Assessment and Outlook Tool
SCR	Strategic Capability Roadmap

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In 2005, the Canadian Forces' (CF) Chief of Defence Staff announced the commencement of the transformation of the CF. As with any complex organization, transformation of its structure and processes is not simple. However, success of such a transition "depends upon leadership first identifying and understanding the thematic components of the past, and then, learning how to adapt and exploit the thematic strengths 'today' for the benefit of 'tomorrow' ". While several themes have been identified within the CF transformation, one in which the operational research community plays a vital support role is strategic decision-making. Strategic decision-making, in the context of defence acquisitions, has traditionally been described as a reactive process. In an effort to migrate defence acquisitions towards a more proactive process, a rational forward-looking decision-making process was developed: the Force Development (FD) process. At its core is Capability Based Planning (CBP), whose analytical process and associated tools provide decision-makers with an objective assessment of capability deficiencies, adequacies, and affluences. This objective assessment is central to the following defence acquisition trade-off analysis, whose output is a cost-effective strategic capability roadmap.

The FD process and first generation CBP analytical process have been recently reported. Development of the second generation CBP analytical process has been completed, which focused on advancement of the process and tools. In this technical memorandum a brief summary of the FD process is presented. This is followed by an overview of the second generation CBP analytical process, including a description of its methods with an emphasis on how they work together and their advancements since the first generation.

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